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Analysis of olive grove residual biomass potential for electric and thermal energy generation in Andalusia (Spain)

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ABSTRACT

As fossil fuels are not only a limited resource, but also contribute to global warming, a transition towards a more sustainable energy supply is urgently needed. Therefore, today's environmental policies are largely devoted to fostering the development and implementation of renewable energy technologies. One important aspect of this transition is the increased use of biomass to generate renewable energy. Agricultural residues are produced in huge amounts worldwide, and most of this residue is composed of biomass that can be used for energy generation. Consequently, converting this residue into energy can increase the value of waste materials and reduce the environmental impact of waste disposal. This paper analyses the situation of biomass energy resources in Andalusia, an autonomous community in the south of Spain. More specifically, biomass is the renewable source which most contributes to Andalusian energy infrastructure. The residual biomass produced in the olive sector is the result of the large quantity of olive groves and olive oil manufacturers that generate byproducts with a potentially high energy content. The generation of agricultural and industrial residues from the olive sector produced in Andalusia is an important source of different types of residual biomass that are suitable for thermal and electric energy since they reduce the negative environmental effects of emissions from fossil fuels, such as the production of carbon dioxide.

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1. Introduction

Energy is essential to economic and social development and a high quality of life. In consequence, energy consumption in developed countries grows at a rate of approximately 1% per year, and that of developing countries, at a rate of 5% per year [1]. Therefore, much of the world's energy is currently produced and consumed in ways that could not be sustained if technology was to remain at

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its present level and if the overall energy demand was to increase substantially [2]. However, oil and natural gas reserves can only cover consumption at this rate for the next 40 years in the case of oil, and for the next 60 years in the case of natural gas.

From a purely environmental perspective, the emissions currently generated by the use of fossil fuels are the source of serious environmental problems, such as acid rain, the greenhouse effect, and holes in the ozone layer, which in many cases are irreversible [1,3,4]. Solutions to control atmospheric emissions of greenhouse gases as well as other gases and substances require potential long-term actions for sustainable development. Such actions should be geared to enhancing energy production, transmission, distribution, and consumption [2]. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions because they are both renewable and sustainable [3]. Even more important, renewable energy produces scarcely any waste products such as carbon dioxide or other chemical pollutants. It thus has a minimal impact on the environment [5].

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, which was adopted in December 1997, was a crucial turning point in the international effort to promote the use of renewable energy worldwide. After the original Framework Convention was signed at the Earth Summit in Rio de Janeiro in 1992, growing evidence of climate change has spurred many countries to increase their support of renewable energy. Even more ambitious efforts to promote renewables can be expected as a result of the Kyoto pact, which includes legally binding emissions limits for industrial countries, and for the first time, specifically identifies the promotion of renewable energy as a key strategy for reducing greenhouse gas emissions [6].

For 2010, the European Union set ambitious targets for the share of renewable energies in total energy and electricity consumption and for biofuels. The specific energy targets in the European Union for 2010 (EU-25) were to increase the share of renewable energies from 6% to 12% of the gross energy consumption, of green electricity from 14% to 21% of the gross electricity production and of liquid biofuels to 5.75% of the total fuel consumption [7]. Amongst renewable energy sources, the largest contribution (63%) comes from biomass. Today, energy from biomass already provides approximately 4% of the total EU energy supply. This energy is predominantly used for heat, and to a lesser extent, for combined heat and power (CHP) applications. By 2010, it was expected that biomass would provide as much as 8% of the total EU energy supply. The European Commission estimates that reaching the target of a 12% share of renewable energy in total energy consumption in Europe will require around 130 Mtoe of biomass [8].

In this regard, Spain has taken up the challenge in this effort to establish a new energy model, and is working to develop legal, regulatory, and budgetary tools to promote the transformation process that is crucial to the fulfilment of energy objectives. Amongst these were the *Plan de Energías Renovables* (PER) (2005–2010), that has now been followed by the *Plan de Acción Nacional de Energías Renovables* (PANER) (2010–2020). Both of these plans have replaced the *Plan de Fomento de las Energías Renovables* (2000–2010), which did not produce satisfactory results. The PER was enacted so that renewable resources would cover at least 12% of the total energy consumption (16.6 Mtoe) by the year 2010. In addition, new goals were incorporated, and adopted after the previous plan [9]. Furthermore, the implementation of this plan expands the scope of the energy policy. More specifically, it aspires to a new energy model that promotes structural changes in the system and the consolidation of an energy culture imbued with a collective awareness that energy is a scarce and valuable resource.

The structural reorientation of the Spanish energy system evidently requires a repositioning in regards to the best possible use of the country's energy resources and the overall definition of a model for energy production and use. Such a model should be fully adapted to the climatic, cultural, and economic conditions of the different regions, where energy policies are generally implemented through regional development plans, such as the *Plan Energético de Andalucía* 2003–2006 (PLEAN) in Andalusia, which was followed by the *Plan Andaluz de Sostenibilidad Energética* (PASENER) 2007–2013.



Fig. 1. Geographical location of Andalusia.

In this regard, the PASENER is a new energy plan based on the commitments in the Kyoto Protocol. It incorporates changes in energy policies and envisages a new energy model that consolidates an energy culture that considers energy as a scarce and valuable resource. Its strategic objectives are the following: (i) to give priority to renewable energy sources in order to increase energy self-sufficiency in Andalusia; (ii) to protect the environment; (iii) to create an energy model adapted to the conditions of the region.

Evidently, Andalusia is in a privileged position because of its capacity for wind power production, as well as its abundant solar catchment. However, biomass is the renewable source which most contributes to Andalusian energy infrastructure [10] because of the availability of residual biomass. This is hardly surprising since farming is the main economic activity in Andalusia. In fact, there are 4.7 million agricultural hectares (57% of the territory). Of these hectares, 1.4 million are olive groves, which are the main source of residual biomass in the Autonomous Community [11,12]. This study analyzes the potential of olive grove residual biomass for the production of electrical and thermal renewable energy from biomass in Andalusia (Spain).

2. Energy situation in Andalusia

2.1. Geographic location and agricultural activity

Spain is located in southwestern Europe and comprises about 84% of the Iberian Peninsula (Fig. 1). Its total area is 504,782 km^2 of which 499,542 km^2 is land and 5240 km^2 is water. It is divided into 17 autonomous communities and 52 provinces.

The Autonomous Community of Andalusia is located in the south of Spain, between latitudes 37° and 42°N, with a surface area of 87,268 km^2, approximately 17.68% of the territory in Spain. The region is divided into eight provinces: Huelva, Seville, Cordoba, Jaen, Almeria, Granada, Malaga and Cadiz. It is the most densely populated autonomous community in the country (8,285,692 inhabitants in 2009), which amounts to 18% of the national population.

Of the various economic sectors, the primary sector (agricultural activities, hunting, silviculture and fishing) is more important in Andalusia than in the rest of Spain, and in 2003 represented 6% of the gross added value of Andalusian economy. This result is an excellent indicator of the importance of this sector in Andalusia, which generates a high percentage of employment (27% of all agricultural jobs in Spain) [12].

Table 1
Energy balance of Andalusia in 2008 [10].

Unit: ktoe	Coal and derivative products	Crude oil and derivative products	Natural gas	Renewable energies	Electric energy	Derivative energies (heat)[a]	Total
Production	23.4	0.0	15.4	1668.3	0.0	0.0	1957.1
Recoveries	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exchange balance (imp–exp)	1823.0	10,135.8	6438.8	−58.2	286.1	0.0	18,625.5
Stock variation (initial–final)	−355.9	45.6	70.7	0.0	0.0	0.0	−239.6
Bunkers (maritime transport)	0.0	199.2	0.0	0.0	0.0	0.0	199.2
Gross internal consumption	1740.5	10,380.6	6524.9	1610.0	286.1	0.0	20,542.2
Available for final consumption	31.6	8871.3	2391.6	750.6	3134.9	33.9	15,213.9
Non-energetic final consumption	0.0	1312.7	276.7	0.0	0.0	0.0	1589.4
Energetic final consumption	31.6	7558.6	2115.1	750.6	3134.9	33.9	13,624.7

[a] The column called “Derivative energies (heat)” shows the production of heat for sale.

Table 2
Energetic consumption distribution by sectors in Andalusia [10].

Unit: ktoe	Coal and derivative products	Crude oil and derivative products	Natural gas	Renewable energies	Electric energy	Derivative energies (heat)*	Total
Industry	31.6	682.4	1786.1	466.5	789.6	33.9	3790.1
Transport	0.0	5405.3	6.3	98.0	33.0	0.0	5542.6
Primary (agriculture and fishing)	0.0	896.7	88.2	7.5	126.1	0.0	1118.6
Service sector	0.0	33.9	122.5	56.3	1065.6	0.0	1278.3
Residential	0.0	540.3	112.0	122.3	1120.6	0.0	1895.2
Energetic final consumption	31.6	7558.6	2115.1	750.6	3134.9	33.9	13,624.7

*Quantity of produced heat used for sale.

2.2. Energy balance

Andalusia estimates its primary energy consumption at 20.5 Mtoe, based on the use of fossil fuels imported as crude oil (50.5%), natural gas (31.7%) and coal (8.5%). Fossil fuels are not produced in Andalusia because there is no crude oil. Since there are only five deposits of natural gas and four deposits of coal in the region [13], its self-sufficient energy supply is estimated at 9.1%.

Conversely, in this same region, 1668.3 ktoe of energy comes from renewable sources. Of this energy, 58.2 ktoe are exported. The gross internal consumption of renewable energies is thus 1610 ktoe, with 750.6 ktoe available for final energy consumption. This is 5.5% of the 13.6 Mtoe final energy consumption in the region (Table 1), which is mainly used by the industrial and domestic sectors (Table 2).

Of the various renewable energies, biomass is the source which most contributes to Andalusian energy infrastructure. It comes to 6.3% of the total primary energy consumption and 78.7% of the renewable energy consumption (Fig. 2). The progressive increase in renewable energy sources is mainly due to the use of biomass for energy. The rain calendar as well as the agricultural crops and harvests have a bearing on this contribution. In Andalusia, one of the most important crops is olives [14]. In 2008, the contribution of primary energy from biomass was 40.5% (365.1 ktoe), which was higher than in 2007 (Fig. 2).

2.3. Renewable energy infrastructure and its policy in Andalusia

Andalusia, while deficient in fossil energy resources, is very rich in renewable resources [13]. It is privileged in this respect because of its capacity for wind power production, and abundant solar catchment. It also has a large quantity of available residual biomass stemming from its great potential for producing energy-yielding crops. For these reasons, conversion to the industry of renewable energy, and more concretely, that of the generation of biomass from agricultural residues, is an opportunity that demands innovation as well as positive action geared towards the generation of knowledge.

Table 3 shows the installed power capacity for each renewable technology in Andalusia. It also specifies the attainment level

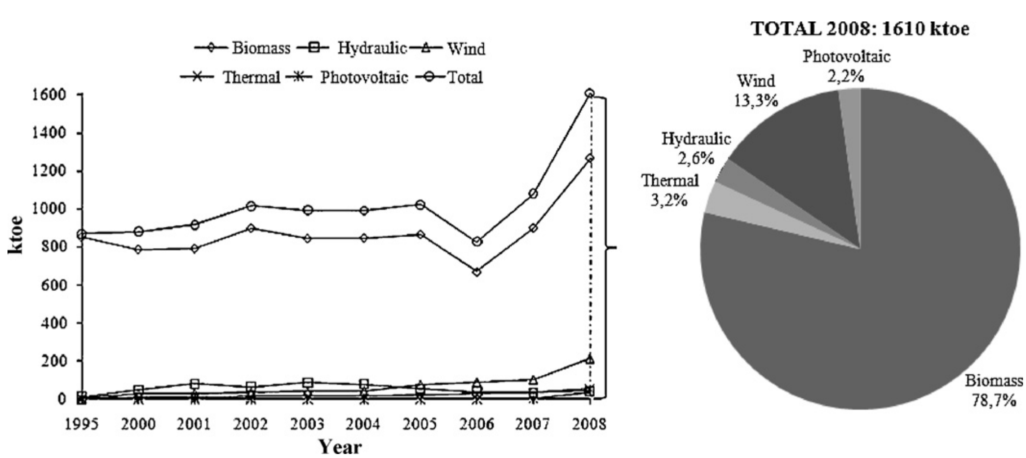


Fig. 2. Evolution of total renewable primary energy consumption in 2008 in Andalusia [10].

Table 3
PLEAN and PASENER objectives [13,14].

		2006	PLEAN objectives 2006	Degree of compliance 2006 (%)	PASENER objectives 2007	PASENER objectives 2010	PASENER objectives 2013
Hydraulic (special regime)	MW	129.8	107.2	121.1	129.8	137.8	148.0
Hydraulic (ordinary regime)	MW	464.2	–	–	464.2	476	476
Wind	MW	607.9	2700	22.5	1284	4000	4800
Solar photovoltaic (insulated)	MWp	5.8	6.1	95.1	36.2	55.4	100
Solar photovoltaic (connected)	MWp	15.4	4.4	348.7			
Solar thermal	m^2	347,182	411.5	84.4	407,000	765,228	1,341,554
Solar thermoelectric	MW	11	100	11	60	250	575
Biomass thermal	ktoe	367.5	643	57.2	583.5	615.6	649.0
Biomass electric	MW	164.6	164	100.4	169.9	209.9	256.0
Biofuels consumption	ktoe	36.1	90	40.1	263.7	2000	2300

of the objectives established in the *Plan Andaluz de Sostenibilidad Energética* (PASENER) 2007–2013. The goal is for renewable energies to cover 12% of Andalusian energy consumption in 2010 and 25.4% of this consumption in 2013. In the case of biomass, it is necessary to distinguish between biomass for the generation of electricity and biomass for thermal use. Since the enactment of the *Plan Energético de Andalucía* (PLEAN) 2003–2006, the required levels for thermal biomass have not as yet been attained, though in the case of electricity biomass, the goal has been reached (Table 3). The reason for this was the transfer of the little fuel available in 2006 to electricity generation plants and the exportation of biomass during this same period to European countries [13]. When the *Plan Energético de Andalucía* (PLEAN) 2003–2006 was in force, biomass was exported to other European Union countries, mainly because of a compensation system in Spain, which could not compete with the prices of this biofuel in other countries. This situation was remedied with the passing of Royal Decree RD 661/2007, which was an important advance since it subsidized installations that used biomass to generate electricity [14].

At the end of 2009, the total power capacity available in installations in the Autonomous Community of Andalusia came to 14051 MW. Renewable sources provided 4419 MW (equivalent to 877.2 ktoe/year, which is the energy consumption of over two million homes). It is significant that 62% of this amount was produced with biomass [15].

3. Biomass potential in Andalusia

Biomass is the renewable energy that most contributes to the energy system in Andalusia (Fig. 2). This region has a cultivated land surface of 8,759,531.18 ha. Approximately 40% of this land is forest and 60% is farmland, of which certain crops cover a total surface of 1,937,107.76 ha [16].

3.1. Biomass potential

The biomass potential in Andalusia is about 3327 ktoe/year [13]. Of this annual amount of biomass, 1434 ktoe is obtained from agricultural residues, of which approximately 50% is olive tree residues (803 ktoe/year) whereas the other half is mainly obtained from sunflowers, cotton and fruit trees (Table 4). This was the capacity necessary to generate 5% of the primary energy consumption of Andalusia in 2007 [17,18]. On the other hand, since olive oil industries generate 77.25% of the industrial residual biomass (Table 4), the olive sector can be regarded as the greatest producer of residual biomass in Andalusia.

The energy exploitation of biomass allows the sustainable replacement of fossil fuels, increases self-sufficiency and energy diversification, and contributes to the development of rural areas. Furthermore, biomass is a renewable energy that can be used as an energy source for electricity, heating, and vehicle transport [17], and reduces 890 g CO_2/kWh if it is used instead of oil. Biomass is a fuel of biological origin, such as woody biomass. If properly cultivated and managed, biomass does not contribute to climate change through emissions of CO_2 to the atmosphere because it absorbs the same amount of carbon in growing as it releases when consumed as fuel. In the future, CO_2 emissions from power and heat generation will have to be greatly reduced to meet environmental constraints and commitments [19].

The final use of biomass depends mainly on the characteristics of the raw material. Most of the biomass in Andalusia generates electricity (45%) and thermal energy (40%), which is mainly used in domestic heating systems (13%) and olive oil industries (14%) due to the abundance of olive groves and their proximity to this type of industry (Fig. 3).

3.2. Olive grove residual biomass in Andalusia

Olive groves are particularly relevant in Andalusia because of their importance in the region and more concretely, for the environmental management and energy use of the residues from olive oil industries and olive grove maintenance [20]. In fact, Andalusia has specific legislation concerning olive groves, which enhances the

Table 4
Biomass potential in Andalusia [13,17].

	ktoe/year
Total biomass potential in Andalusia	3327
Agricultural residues	1434
Olive grove	803
Fruit trees	86
Corn	72
Sunflowers	186
Greenhouse residues	100
Rice	43
Cotton	143
Industrial residues	589
Olive oil industry	455
Bark	35
Rice husk	19
Cotton	15
Nuts	17
Wood	41
Olive stones	2
Sugar refinery	4
Cork	1
Forestry residues	136
Quercus	59
Eucalyptus	53
Pine	18
Poplar	7
Energy crops	559
Cynara	559
Biodegradable	609
MSW	54
Mud	43
Animal waste	15

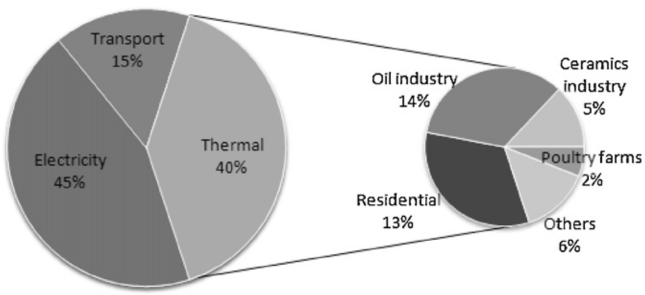


Fig. 3. Biomass energy uses in Andalusia [10].

Table 5
Characteristics of olive trees residues [16].

	Olive pruning residues	Olive-pomace	*Orujillo*	Olive stones
Moisture content (%weight)	10.95	55.29	12.69	13.12
Lower heating value (kcal/kg dry basis)	4300	4250	4300	4500

efficient use of water and energy, and promotes the use of renewable energies, in particular of biomass [21]. These regulations were passed in order to conserve energy and generally improve energy efficiency in the olive sector. The goal is to foment the energy exploitation of agricultural and industrial residues, the production of energy from biomass, and the use of renewable energies.

There are 1.4 million hectares of olive crops in Andalusia [11], producing an average of 4 million tons of olives per year [17]. Of this quantity, 3.7 million tons per year are used to make olive oil (800,000 tons/year), and the rest to obtain olives (300,000 tons/year), to be consumed as table olives. Furthermore, olive crops generate a variety of energy residues, such as olive pruning residues (4.2 million tons/year of branches and leaves that can be pelletized for domestic heating), olive stones (suitable for domestic and industrial heating or electricity production), olive-pomace and *orujillo* [22,23], residues that have been used traditionally for domestic heating in rural areas.

One hectare of olive grove generates three tons of pruning residues (Fig. 4). This means that about four million tons are generated per year in Andalusia, most of which are now illegally burnt or left on the ground to generate greenhouse effect gases [24]. Table 5 shows some of the physical and chemical properties of the residual biomass obtained from olive groves that determines their end use. The low heating value is similar for all the residues, but they have different moisture content, especially in the case of olive-pomace with 55.29% of moisture content in weight.

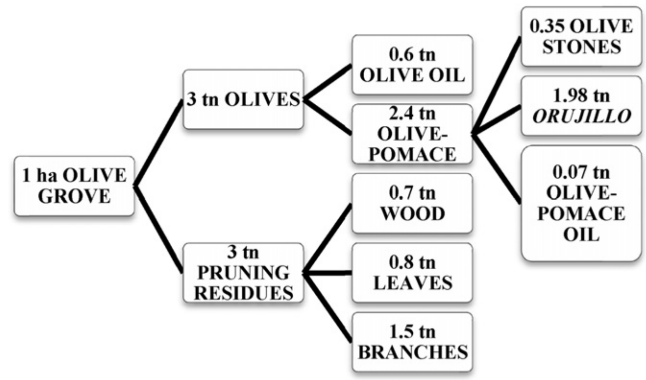


Fig. 4. Biomass potential from olive grove [17].

3.2.1. Electricity biomass

In Andalusia, there are 19 plants that use biomass to generate a total of 205.3 MW of electrical energy (Table 6). This amounts to 1.46% of the total power capacity of 14,051 MW available in existing installations in the Autonomous Community. This quantity is very near to the objectives established in the PASENER for the year 2010 (Table 3), signifies a reduction of approximately 8% of the CO_2 emissions [13]. The majority of these installations use olive trees residues as fuel though there are plants that consume greenhouse residues, wood, and sugar cane bagasse [17]. Olive-pomace, *orujillo*, and olive stones are the olive tree residues that are best for producing electrical energy because their lower bulk density, and in the case of olive-pomace, their higher moisture content (Table 5), make them less effective for domestic heating systems.

3.2.2. Thermal biomass

The demand for heating accounts for a significant portion of the total energy demand in the world today. The building sector consumes 35.3% of the final energy demand of which 75%

Table 6
Electric energy generation plants with biomass as fuel in Andalusia [17].

	Power (MW)	Fuel	Locality	Province
La Loma	16.0	*Orujillo*	Villanueva del Arzobispo	Jaen
Vetejar	12.9	Olive pomace	Palenciana	Cordoba
El Tejar Autogeneracion	5.7	Olive pomace	Palenciana	Cordoba
Agroenergética de Baena	20.0	Olive pomace	Baena	Cordoba
Hnos. Santamaria Muñoz E Hijos	1.7	*Orujillo*	Lucena	Cordoba
Extragol	9.1	*Orujillo*, pruning residues, energy crops	Villanueva de Algaidas	Malaga
Albaida Recursos Naturales I	1.7	Greenhouse residues	Nijar	Almeria
Albaida Recursos Naturales II	1.7	Greenhouse residues	La Mojonera	Almeria
Tradema	2.0	Wood	Linares	Jaen
Fuente de Piedra	8.0	*Orujillo*	Fuente de Piedra	Malaga
Biomasa Puente Genil	9.8	Orujillo	Puente Genil	Cordoba
Bioenergia Santamaria	14.3	Orujillo	Lucena	Cordoba
Bioenergetica Egabrense	8.0	Orujillo	Cabra	Cordoba
ENCE I	40.9	Wood	San Juan del Puerto	Huelva
ENCE II	27.0	Wood	San Juan del Puerto	Huelva
Agroenergetica de Algodonales	5.4	Olive pomace	Palenciana	Cordoba
Severaes	0.1	Olive tree pruning	Cañete de las Torres	Cordoba
Bioenergetica de Linares	15.0	Orujillo, agricultural and forestry residues, energy crops	Linares	Jaen
Aldebaran energia del Guadalquivir	6.0	Chips, cereal straw	Andujar	Jaen
Total	205.3			

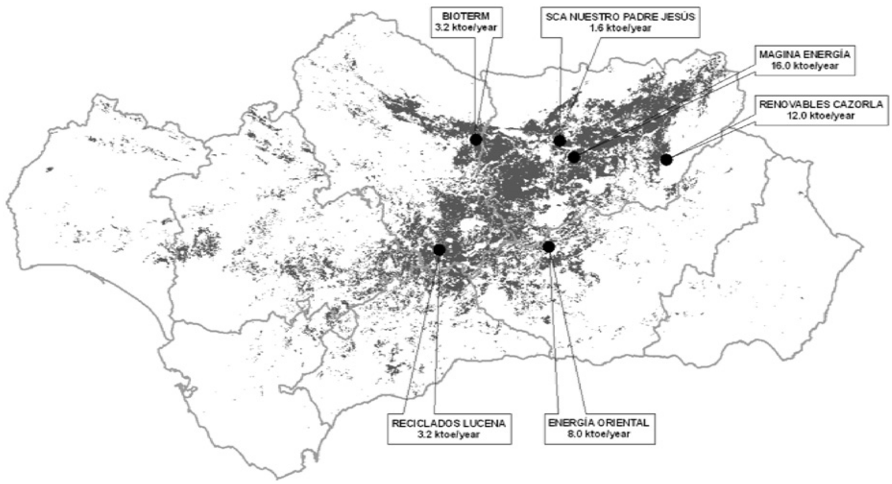


Fig. 5. Olive groves and industrial pellets production plants operating in Andalusia [18].

is for space and domestic water heating [25]. Renewable energy sources used for heating and cooling purposes have received relatively little attention compared with those used to generate electricity and to produce transport fuels. This is surprising because the demand for heat consumes the largest share of the primary energy supply. Renewable energy sources can thus offer a practical alternative to fossil fuels under many circumstances [26]. The potential to increase the use of solar, geothermal, and biomass resources for renewable energy heating is therefore large [27].

In Andalusia, there is a regulatory framework of economic incentives to foment the environment and sustainable energy development. The objective of these measures is to improve environmental protection through energy saving in new and existing buildings. They stress the need to improve the efficient use of energy in the main consumption sectors, such as the industrial, service, and transportation sectors [28]. These economic incentives allow Andalusians to implement more environmentally friendly project in their businesses and homes, and thus reduce fossil fuel consumption.

Biomass consumption for thermal applications during the year 2008 was approximately 613.55 ktoe. This biomass was mainly obtained from olive-pomace and olive stones. This produced a carbon dioxide reduction of 1895.87 metric tons [29] in Andalusia. Moreover, the use of standardized pellets from olive pruning residues would permit the use of these residues in efficient combustion processes. Nevertheless, certain characteristics, such as the higher ash content of olive tree pellets [23] in comparison with other European pellets, have raised doubts concerning their use in thermal applications, especially in domestic heating systems.

Pelletized biomass made from agricultural and forestry products and residues are rapidly becoming an important renewable energy source for industrial and domestic purposes [30]. The pelletization of biomass is a mass and energy densification for materials that possess low bulk densities. The typical bulk density of biomass chips is less than 150 kg/m^3 while that of wood pellets is typically over 600 kg/m^3 [31]. In the pelletizing process, raw material is dried, ground, homogenized, and densified, which reduces transportation costs, improves storage, and results in better handling characteristics with less dust formation, besides providing potential storage for off-season utilization [31].

Andalusia is in the process of improving its infrastructure, and has become the first Spanish region in densified biofuel production, with 13 industrial pellet production plants. Six of these plants are in operation, and are producing 44 ktoe/year. All of them are strategically located near the olive groves to be able to use olive pruning residues (Fig. 5). There are currently three more plants under construction in Jaen that will produce 34.6 ktoe. This will be in addition to the energy generated by the other plants, which is steadily increasing.

4. Conclusions

The use of biomass as an energy resource entails significant socioeconomic and environmental benefits, such as the following: (i) biomass is an abundant resource, and its renewability is a guarantee of sustainable use; (ii) biomass reduces atmospheric emissions so that the net cycle of CO_2 does not contribute to the greenhouse effect; (iii) biomass is relevant to national economies since it eliminates the need to import fossil fuels.

Andalusia is very rich in renewable resources, especially in biomass, which in this region provides 6.3% of the total primary energy consumption and 78.7% of the renewable energy consumption. Much of this residual biomass is produced by the olive sector, which generates pruning residues and olive oil industrial residues, such as olive-pomace, *orujillo*, and olive stones. The management of these agricultural and industrial residues is actively encouraged by the Andalusian regional government, thanks to specific legislation pertaining to olive groves. These regulations foment the use of biomass with a view to improving energy conservation and efficiency in the olive sector.

Biomass can be used to generate electricity, thermal energy and biofuels for transportation. However, its final use depends on the characteristics of the raw material. Government objectives have been fulfilled regarding the use of biomass to produce electrical energy. In contrast, the use of biomass for thermal energy is still considerably below the levels desired. This situation is now being corrected, and the production of densified biomass has increased in Andalusia in order to meet the demand for space and domestic water heating in the building sector. Economic incentives are also offered to encourage people to implement environmentally friendly projects.

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References

[1] Muneer T, Asif M, Munawwar S. Sustainable production of solar energy with particular reference to the Indian economy. Renewable and Sustainable Energy Reviews 2005;9:444–73.
[2] Kaygusuz K, Sari A. Renewable energy potential and utilization in Turkey. Energy Conversion and Management 2003;44:459–78.
[3] Dincer I. Renewable energy and sustainable development: a crucial review. Renewable and Sustainable Energy Reviews 2000;4:157–75.
[4] Rosen MA. Assessing energy technologies and environmental impacts with the principles of thermodynamics. Applied Energy 2002;72:427–41.
[5] Hoogwijk M, Faaij A, Van den Broek R, Berndes G, Gielen D, Turkenburg W. Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy 2003;25:119–33.
[6] Flavin C, Dunn S. Climate of opportunity: renew energy after Kyoto. Renew Energy Policy Project; 2008. Available from http://www.repp.org/.
[7] European Commission (EC). Biomass: green energy for Europe; 2005.
[8] European Commission (EC). The share of renewable energy in the European Union. COM; 2004, 366 final.
[9] Instituto para la Diversificación y Ahorro de la Energía (IDAE). Plan de Energías Renovables en España 2005–2010; 2005.
[10] Agencia Andaluza de la Energía (AAE). Datos energéticos de Andalucía en 2008; 2009.
[11] National Statistics Institute of Spain (INE). Data base; 2003.
[12] Junta de Andalucía. Programa de Desarrollo Rural de Andalucía 2007–2013; 2007.
[13] Consejería de Innovación, Ciencia y Empresa. Plan Andaluz de Sostenibilidad energética (PASENER) 2007–2013; 2007.
[14] BOJA no. 40. Decreto 279/2007, de 13 de noviembre por el que se aprueba el Plan Andaluz de Sostenibilidad Energética (PASENER) 2007–2013; 2007.
[15] EUROPAPRESS. Andalucía alcanza los casi 4.000 megavatios de potencia energética renovable en el primer semestre; 2010.
[16] European Commission (EC). Potencial y aprovechamiento energético de la biomasa del olivar en Andalucía; 2002.
[17] Agencia Andaluza de la Energía (AAE). La situación de la biomasa en Andalucía en enero de 2008; 2008.
[18] Agencia Andaluza de la Energía (AAE). Panorama actual de la biomasa en Andalucía. Orden de desarrollo energético sostenible; 2010.
[19] Wahlund B, Yan J, Westermark M. Increasing biomass utilisation in energy systems: a comparative study of CO_2 reduction and cost for different bioenergy processing options. Biomass and Bioenergy 2004;26:531–44.
[20] BOJA no. 2. Resolución de 22 de diciembre de 2009, de la Secretaría General de Universidades, Investigación y Tecnología, por la que se establece para la convocatoria de 2010 de los proyectos de investigación de excelencia, una línea específica de investigación sobre diversos aspectos del olivar y el aceite de oliva.
[21] Junta de Andalucía. Consejería de Agricultura y Pesca. Proyecto de ley del olivar en Andalucia; 2009.
[22] Arjona R, García A, Ollero P. The drying of alpeorujo, a waste product of the olive oil mill industry. Journal of Food Engineering 1999;4:229–34.
[23] Ollero P, Serrera A, Arjona R, Alcantarilla S. The CO_2 gasification kinetics of olive residue. Biomass and Bioenergy 2003;24:151–61.
[24] Junta de Andalucia. Análisis de la incidencia de la supresión de la quema de residuos agrícolas sobre la reducción de emisiones de gases contaminantes en Andalucía; 2009.
[25] International Energy Agency (IEA). Barriers to technology diffusion: the case of solar thermal technologies; 2006.
[26] International Energy Agency (IEA). Renewables for heating and cooling; 2007.
[27] Jurczak C. Seminar renewable heating and cooling – from RD&D to deployment. International Energy Agency; 2006.
[28] BOJA no. 30. Orden de 4 de febrero de 2009, por la que se establecen las bases reguladoras de un programa de incentives para el desarrollo energético sostenible de Andalucia y se efectua su convocatoria para los años 2009–2014.
[29] IPCC. Guidelines for national greenhouse gas inventories, vol. 2; 2006.
[30] Larsson SH, Thyrel M, Geladi P, Lestander TA. High quality biofuel pellet production from pre-compacted low density raw materials. Bioresource Technology 2007;99:7176–82.
[31] Gilbert P, Ryu C, Sharifi V, Swithenbank J. Effect of process parameters on pelletisation of herbaceous crops. Fuel 2009;88:1491–7.